CHAPTER 6

ONSITE TREATMENT METHODS

6.1 Introduction

This chapter presents information on the component of an onsite system that provides "treatment" of the wastewater, as opposed to its "disposal" (disposal options for treated wastewater are covered in Chapter 7). Treatment options included in this discussion are:

1. Septic tanks
2. Intermittent sand filters
3. Aerobic treatment units
4. Disinfection units
5. Nutrient removal systems
6. Wastewater segregation and recycle systems

Detailed design, O&M, performance, and construction data are provided for the first four components above. A more general description of nutrient removal is provided as these systems are not yet in general use, and often involve in-house changes in product use and plumbing. A brief mention of wastewater segregation and recycle options is included, since these also function as treatment options.

Options providing a combined treatment/disposal function, i.e., soil absorption systems, are discussed in Chapter 7.

6.1.1 Purpose

The purpose of the treatment component is to transform the raw household wastewater into an effluent suited to the disposal component, such that the wastewater can be disposed of in conformance with public health and environmental regulations. For example, in a subsurface soil absorption system, the pretreatment unit (e.g., septic tank) should remove nearly all settleable solids and floatable grease and scum so that a reasonably clear liquid is discharged into the soil absorption field. This allows the field to operate more efficiently. Likewise, for a surface discharge system, the treatment unit should produce an effluent that will meet applicable surface discharge standards.

6.1.2 Residuals

No treatment process is capable of continuous operation without experiencing some type of residuals buildup. Removal and disposal of these residuals is a very important and often neglected part of overall system O&M.

Residuals handling is discussed in detail under each individual component in Chapters 6 and 7. Final disposal of residuals is covered in Chapter 9.

6.2 Septic Tanks

6.2.1 Introduction

The septic tank is the most widely used onsite wastewater treatment option in the United States. Currently, about 25% of the new homes being constructed in this country use septic tanks for treatment prior to disposal of home wastewater.

This section provides detailed information on the septic tank, its siting considerations, performance, design, construction procedures, and operation and maintenance. The discussion centers on tanks for single-family homes; tanks for larger flows are discussed where they differ from the single-family model.

6.2.2 Description

Septic tanks are buried, watertight receptacles designed and constructed to receive wastewater from a home, to separate solids from the liquid, to provide limited digestion of organic matter, to store solids, and to allow the clarified liquid to discharge for further treatment and disposal. Settleable solids and partially decomposed sludge settle to the bottom of the tank and accumulate. A scum of lightweight material (including fats and greases) rises to the top. The partially clarified liquid is allowed to flow through an outlet structure just below the floating scum layer. Proper use of baffles, tees, and ells protects against scum outflow. Clarified liquid can be disposed of to soil absorption systems, soil mounds, lagoons, or other disposal systems. Leakage from septic tanks is often considered a minor factor; however, if tank leakage causes the level of the scum layer to drop below the outlet baffle, excessive scum discharges can occur. In the extreme case, the sludge layer will dry and compact, and normal tank cleaning practices will not remove it (1). Another problem, if the tank is not watertight, is infiltration into the tank which can cause overloading of the tank and subsequent treatment and disposal components.

6.2.3 Application

Septic tanks are normally the first component of an onsite system. They must be followed by polishing treatment and/or disposal units. In most instances, septic tank effluent is discharged to a soil absorption field where the wastewater percolates down through the soil. In areas where soils are not suitable for percolation, septic tank effluent can be discharged to mounds or ET beds for treatment and disposal, or to filters or lagoons for further treatment.

Septic tanks are also amenable to chemical addition for nutrient removal, as discussed later in this manual.

Local regulatory agencies may require that the septic tank be located specified distances from home, water well, and water lines to reduce any risk of disease-causing agents from the septic tank reaching the potable water supply. A number of minimum separation distances have been developed for protecting water supplies and homes from septic tank disposal systems, but these are largely arbitrary and depend to a great degree on the soil conditions. Many state and local building codes feature suggested separation distances that should be adhered to in the absence of any extenuating circumstances.

6.2.4 Performance

Table 6-1 summarizes septic tank effluent quality. In addition to the tabulated results, bacterial concentrations in the effluent are not significantly changed since septic tanks cannot be relied upon to remove disease-causing microorganisms. Oil and grease removal is typically 70 to 80%, producing an effluent of about 20-25 mg/l. Phosphorus removal is slight, at about 15%, providing an effluent quality of about 20 mg/l total P.

Brandes (7) studied the quality of effluents from septic tanks treating graywater and blackwater. He found that without increasing the volume of the septic tank, the efficiency of the blackwater (toilet wastewater) treatment was improved by discharging the household graywater to a separate treatment disposal system.

TABLE 6-1

SUMMARY OF EFFLUENT DATA FROM VARIOUS SEPTIC TANK STUDIES

Parameter	Source Ref. (2) 7 Sites	Ref. (3) 10 Tanks	Ref. (4) 19 Sites	Ref. (5) 4 Sites	Ref. (6) 1 Tank
BOD_5					
Mean, mg/l	138	138[a]	140	240[b]	120
Range, mg/l	7-480	64-256	--	70.385	30-280
No. of Samples	150	44	51	21	50
COD					
Mean, mg/l	327	--	--	--	200
Range, mg/l	25-780	--	--	--	71-360
No. of Samples	152	--	--	--	50
Suspended Solids					
Mean, mg/l	49	155[a]	101	95[b]	39
Range, mg/l	10-695	43-485	--	48-340	8-270
No. of Samples	148	55	51	18	47
Total Nitrogen					
Mean, mg/l	45	--	36	--	--
Range, mg/l	9-125	--	--	--	--
No. of Samples	99	--	51	--	--

[a] Calculated from the average values from 10 tanks, 6 series of tests.

[b] Calculated on the basis of a log-normal distribution of data.

Factors affecting septic tank performance include geometry, hydraulic loading, inlet and outlet arrangements, number of compartments, temperature, and operation and maintenance practices. If a tank is hydraulically overloaded, retention time may become too short and solids may not settle or float properly.

A single-compartment tank will give acceptable performance. However, multi-compartment tanks perform somewhat better than single-compartment tanks of the same total capacity, because they provide better protection against solids carry-over into discharge pipes during periods of surges or upset due to rapid digestion.

Improper design and placement of baffles can create turbulence in the tank, seriously impairing settling efficiency. In addition, poor baffles or outlet devices may promote scum or sludge entry to discharge pipes. Obviously, improper operation and maintenance will impair performance. Flushing problem wastes (paper towels, bones, fats, diapers, etc.) into the system can clog piping. Failure to pump out accumulated solids will eventually lead to problems with solids discharge in the effluent.

6.2.5 Design

6.2.5.1 General

Septic tanks for single-family homes are usually purchased "off the shelf," ready for installation, and are normally designed in accordance with local codes.

The tank must be designed to ensure removal of almost all settleable solids. To accomplish this, the tank must provide:

1. Liquid volume sufficient for a 24-hr fluid retention time at maximum sludge depth and scum accumulation (8).

2. Inlet and outlet devices to prevent the discharge of sludge or scum in the effluent.

3. Sufficient sludge storage space to prevent the discharge of sludge or scum in the effluent.

4. Venting provisions to allow for the escape of accumulated methane and hydrogen sulfide gases.

6.2.5.2 Criteria

The first step in selecting a tank volume is to determine the average volume of wastewater produced per day. Ideally, this is done by metering wastewater flows for a given period; but that is seldom feasible, particularly if a septic tank system is being selected for a building still under construction.

In the past, the design capacity of most septic tanks was based on the number of bedrooms per home and the average number of persons per bedroom. Chapter 4 showed that the average wastewater contribution is about 45 gpcd (170 lpcd) (2). As a safety factor, a value of 75 gpcd (284 lpcd) can be coupled with a potential maximum dwelling density of two persons per bedroom, yielding a theoretical design flow of 150 gal/bedroom/day (570 l/bedroom/day). A theoretical tank volume of 2 to 3 times the design daily flow is common, resulting in a total tank design capacity of 300 to 450 gal per bedroom (1,140 to 1,700 l per bedroom).

While not ideal, most state and local codes rely on some version of this method by assigning required septic tank capacities solely by the number of bedrooms (see Table 6-2). Unfortunately, hourly and daily flows from the home can vary greatly. During high flow periods, higher solids concentrations are discharged from the septic tank. Well-designed, two-compartment tanks reduce the effect of peak hour loads.

Another key factor in the design and performance of septic tanks is the relationship between surface area, surge storage, discharge rate, and exit velocity. These parameters affect the hydraulic efficiency and sludge retention capacity of the tank.

Tanks with greater surface area and shallower depth are preferred, because increased liquid surface area increases surge storage capacity; a given inflowing volume creates a smaller rise in water depth and a slower discharge rate and exit velocity. These surges of flow through the tank are dampened as surface area increases. This allows a longer time for separation of sludge and scum that are mixed by turbulence resulting from the influent surge (8).

In addition to increasing the surface area, there are two other means of reducing the exit velocity and reducing the opportunity for solids and scum to escape through the outlet. These are: 1) increase the size of the outlet riser; and 2) reduce the size of the final discharge pipe. The use of a 6-in. (15-cm) outlet riser instead of a 4-in. (10-cm)

TABLE 6-2

TYPICAL SEPTIC TANK LIQUID VOLUME REQUIREMENTS

	Federal Housing Authority	U.S. Public Health Service	Uniform Plumbing Code	Range of State Requirements (9)
Minimum, gal	750	750	750	500 - 1,000
1-2 bedrooms, gal	750	750	750	500 - 1,000
3 bedrooms, gal	900	900	1,000	900 - 1,500
4 bedrooms, gal	1,000	1,000	1,200	1,000 - 2,000
5 bedrooms, gal	1,250	1,250	1,500	1,100 - 2,000
Additional bedrooms (ea), gal	250	250	150	-

outlet riser will reduce the exit velocity from 0.025 ft/sec to 0.011 ft/sec (0.76 cm/sec to 0.34 cm/sec) a reduction of 56% (8).

Use of garbage grinders increases both the settleable and floatable solids in the wastewater and their accumulation rates in the septic tank. U.S. Public Health Service (USPHS) studies indicate that the increase in the sludge and scum accumulation rate is about 37% (10). This means either more frequent pumping or a larger tank to keep the pumping frequency down. A common expedient is to add 250 gal (946 l) to the tank size when garbage grinders are used, although this volume is arbitrary. It is generally a good idea to avoid the use of garbage grinders with onsite systems.

6.2.5.3 Inlet and Outlet Devices

The flow out of a septic tank should carry only minimal concentrations of settleable solids. Higher concentrations can occur if:

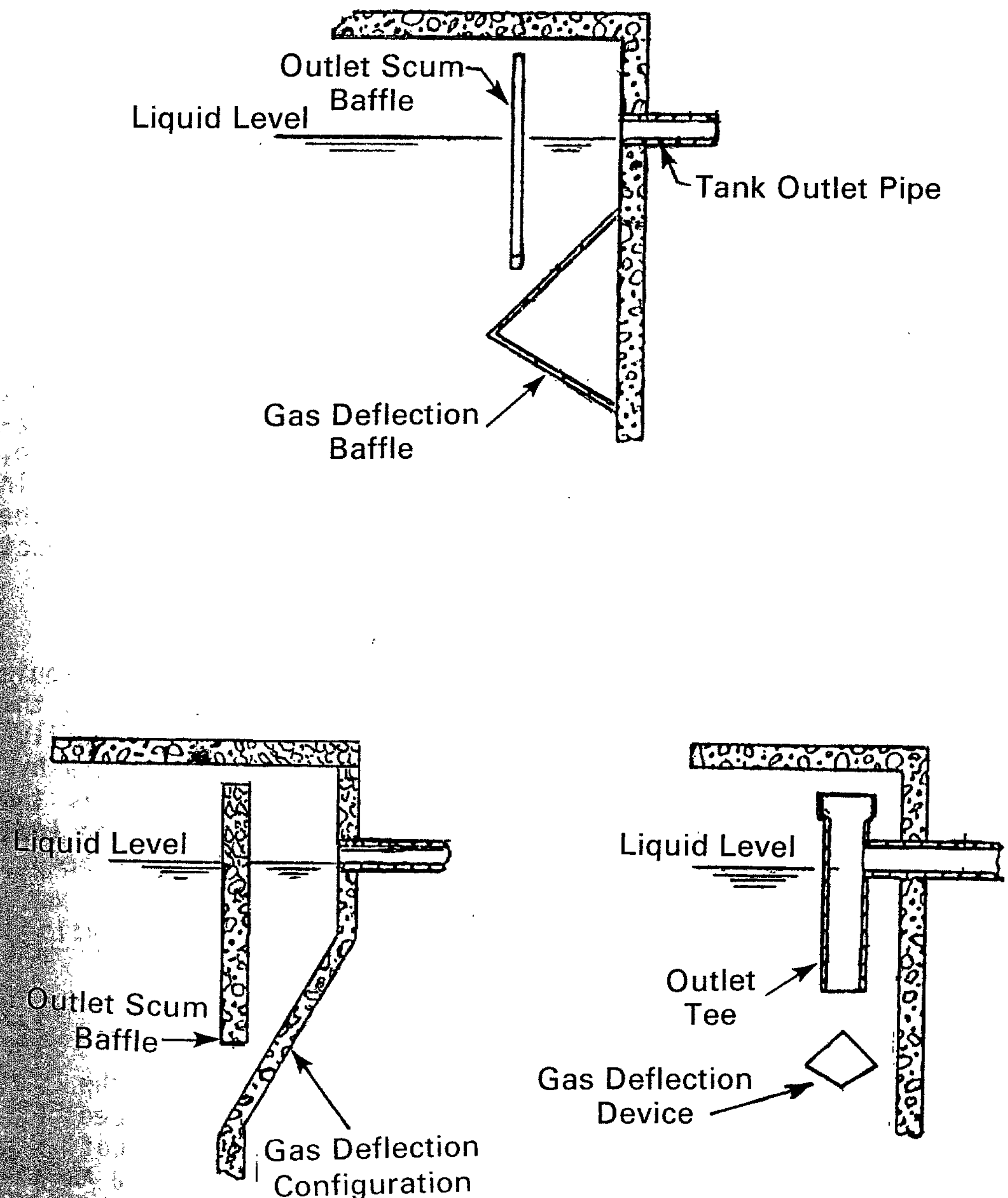
1. The inlet turbulence in a single-compartment tank causes mixing of the sludge with the wastewater in the clear space.
2. The rise velocity of the water in the vertical leg of the outlet tee resuspends previously captured solids.
3. The rising gases produced by anaerobic digestion interfere with particle-settling and resuspend previously captured solids, which then are lost in the effluent.

The inlet to a septic tank should be designed to dissipate the energy of the incoming water, to minimize turbulence, and to prevent short-circuiting. The inlet should preferably be either a sanitary tee or baffle. The baffle should be small enough so that it is flushed out each time, and yet keeps floating solids from blocking the inlet. The invert radius in a tee helps dissipate energy in the transition from horizontal to vertical flow, and prevents dripping that, at the proper frequency, can amplify water surface oscillations and increase intercompartmental mixing. The vertical leg of the inlet tee should extend below the liquid surface. This minimizes induced turbulence by dissipating as much energy in the inlet as possible.

The outlet structure's ability to retain sludge and scum in either the first or second compartment is a major factor in overall task performance. The outlet of a septic tank can be a tee, a baffle, or some special structure (see Figure 6-1). The outlet must have the proper submergence and height above liquid level such that the sludge

FIGURE 6-1

TYPICAL SEPTIC TANK OUTLET STRUCTURES TO MINIMIZE SUSPENDED SOLIDS IN DISCHARGE(11)



and scum clear spaces balance, and proper venting of sludge gases is provided (see Figure 6-2). Although the Manual of Septic Tank Practices recommends an outlet submergence equal to 40% of the liquid depth, other studies have shown that shallower submergence decreases solids discharges and allows for greater sludge accumulation, and thus for less frequent pumping (8). Table 6-3 summarizes the results of these studies.

As shown in Figure 6-1, various types of gas deflection baffles and wedges have been developed to prevent gas-disturbed sludge from entering the rising leg of the outlet.

6.2.5.4 Compartmentation

Recent trends in septic tank design favor multiple, rather than single, compartmented tanks. When a tank is properly divided into compartments, BOD and SS removal are improved. Figure 6-3 shows a typical two-compartment tank.

The benefits of compartmentation are due largely to hydraulic isolation, and to the reduction or elimination of intercompartmental mixing. Mixing can occur by two means: water oscillation and true turbulence. Oscillatory mixing can be minimized by making compartments unequal in size (commonly the second compartment is 1/3 to 1/2 the size of the first), reducing flow-through area, and using an ell to connect compartments (1).

In the first compartment, some mixing of sludge and scum with the liquid always occurs due to induced turbulence from entering wastewater and the digestive process. The second compartment receives the clarified effluent from the first compartment. Most of the time it receives this hydraulic load at a lower rate and with less turbulence than does the first compartment, and, thus, better conditions exist for settling low-density solids. These conditions lead to longer working periods before pump-out of solids is necessary and improve overall performance.

6.2.5.5 Access and Inspection

In order to provide access and a means to inspect the inside of the septic tank, manholes should be provided. Manholes are usually placed over both the inlet and the outlet to permit cleaning behind the baffles. The manhole cover should extend above the actual septic tank to a height not more than 6 in. (15 cm) below the finished grade. The actual cover can extend to the ground surface if a proper seal is provided to prevent

FIGURE 6-2

SEPTIC TANK SCUM AND SLUDGE CLEAR SPACES (8)

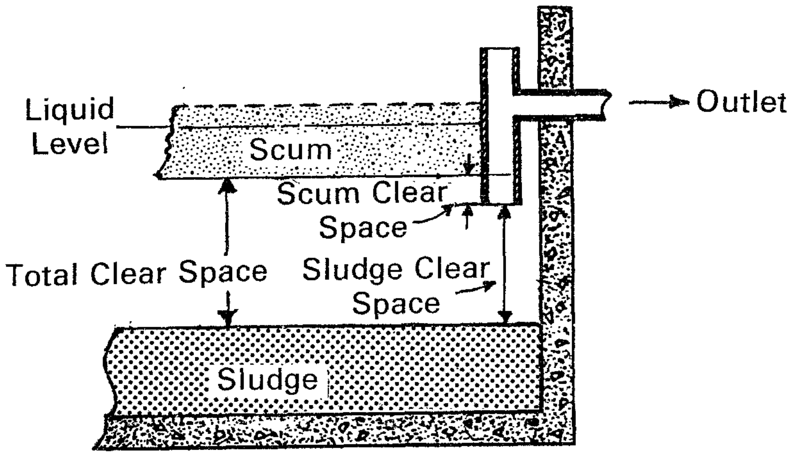


TABLE 6-3

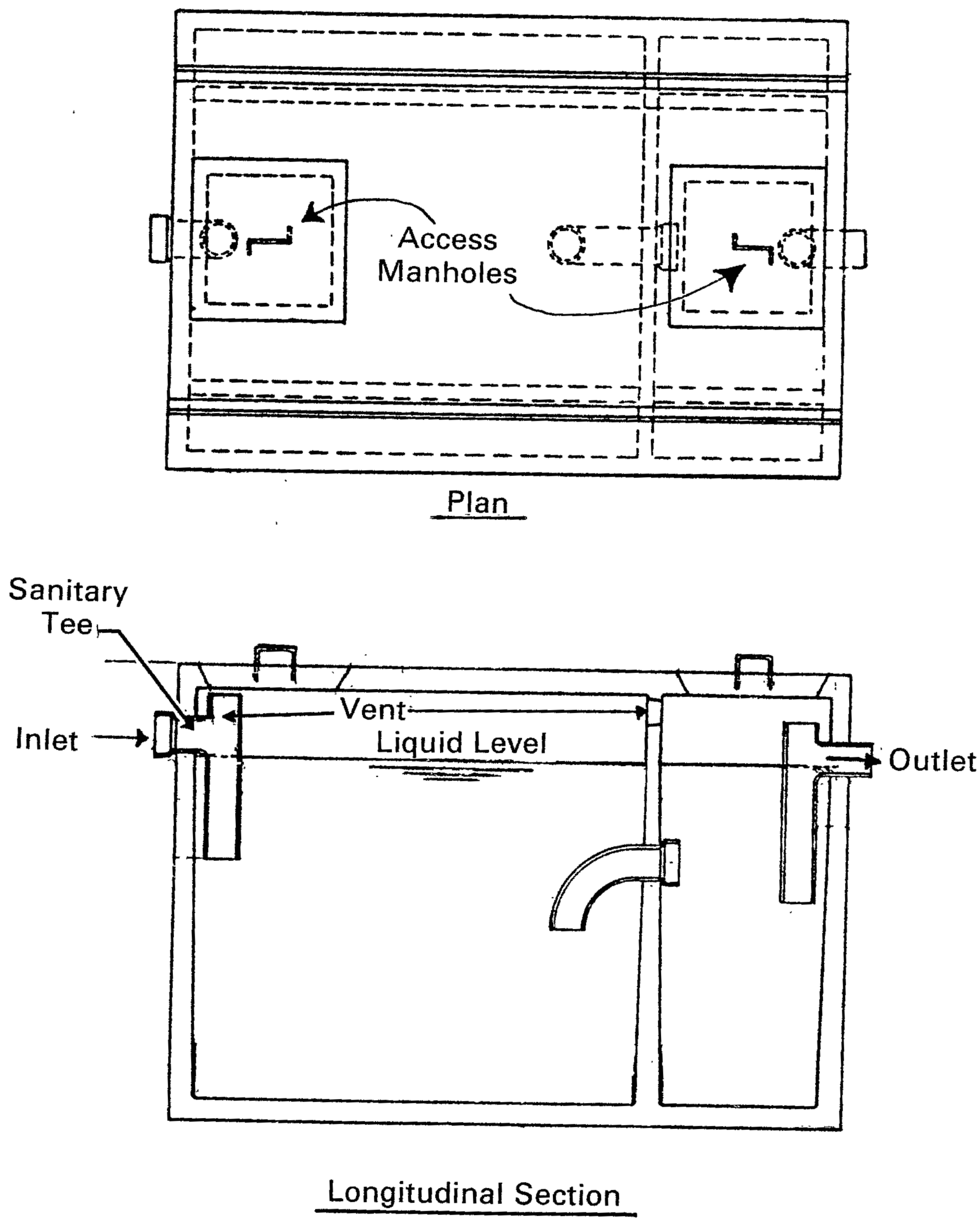
LOCATION OF TOP AND BOTTOM OF OUTLET TEE OR BAFFLE (12)

Total Liquid Tank Capacity gal	Tank Receiving Sewage		Tank Receiving Sewage and Garbage	
	Projection[a] Above Liquid Level	Penetration[a] Below Liquid Level	Projection[a] Above Liquid Level	Penetration[a] Below Liquid Level
500	12	22	--	--
750	12	24	18	38
1,000	12	26	18	41

[a] Percentage of liquid depth. See Figure 6-2 for diagram.

FIGURE 6-3

TYPICAL TWO-COMPARTMENT SEPTIC TANK



the escape of odors and accidental entry into the tank. In addition, small inspection pipes can be placed over the inlet and outlet to allow inspection without having to remove the manhole.

6.2.5.6 Materials

The most commonly used construction material for septic tanks is concrete. Virtually all individual-home septic tanks are precast for easy installation in the field. The walls have a thickness of 3 to 4 in. (8 to 10 cm), and the tank is sealed for watertightness after installation with two coats of bituminous coating. Care must be taken to seal around the inlet and discharge pipes with a bonding compound that will adhere both to concrete and to the inlet and outlet pipe.

Steel is another type of material that has been used for septic tanks. The steel must be treated so as to be able to resist corrosion and decay. Such protection includes bituminous coating or other corrosion-resistant treatment. However, despite a corrosion-resistant coating, tanks deteriorate at the liquid level. Past history indicates that steel tanks have a short operational life (less than 10 years) due to corrosion (3).

Other materials include polyethylene and fiberglass. Plastic and fiberglass tanks are very light, easily transported, and resistant to corrosion and decay. While these tanks have not had a good history, some manufacturers are now producing an excellent tank with increased strength. This minimizes the chance of damage during installation or when heavy machinery moves over it after burial.

6.2.6 Installation Procedures

The most important requirement of installation is that the tank be placed on a level grade and at a depth that provides adequate gravity flow from the home and matches the invert elevation of the house sewer. The tank should be placed on undisturbed soil so that settling does not occur. If the excavation is dug too deep, it should be backfilled to the proper elevation with sand to provide an adequate bedding for the tank. Tank performance can be impaired if a level position is not maintained, because inlet and outlet structures will not function properly.

Other considerations include:

1. Cast iron inlet and outlet structures should be used in disturbed soil areas where tank settling may occur.

2. Flotation collars should be used in areas with high groundwater potential.

3. The tank should be placed so that the manhole is slightly below grade to prevent accidental entry.

4. The tank should be placed in an area with easy access to alleviate pump-out problems.

5. During installation, any damage to the watertight coating should be repaired. After installation, the tank should be tested for watertightness by filling with water.

6. Care should be taken with installation in areas with large rocks to prevent undue localized stresses.

7. Baffles, tees, and elbows should be made of durable and corrosion-proof materials. Fiberglass or acid-resistant concrete baffle materials are most suitable. Vitrified clay tile, plastic, and cast iron are best for tees and ells.

6.2.7 Operation and Maintenance

One of the major advantages of the septic tank is that it has no moving parts and, therefore, needs very little routine maintenance. A well-designed and maintained concrete, fiberglass, or plastic tank should last for 50 years. Because of corrosion problems, steel tanks can be expected to last no more than 10 years. One cause of septic tank problems involves a failure to pump out the sludge solids when required. As the sludge depth increases, the effective liquid volume and detention time decrease. As this occurs, sludge scouring increases, treatment efficiency falls off, and more solids escape through the outlet. The only way to prevent this is by periodic pumping of the tank.

Tanks should be inspected at intervals of no more than every 2 years to determine the rates of scum and sludge accumulation. If inspection programs are not carried out, a pump-out frequency of once every 3 to 5 years is reasonable. Once the characteristic sludge accumulation rate is known, inspection frequency can be adjusted accordingly. The inlet and outlet structures and key joints should be inspected for damage after each tank pump-out.

Actual inspection of sludge and scum accumulations is the only way to determine definitely when a given tank needs to be pumped. When a tank is inspected, the depth of sludge and scum should be measured in the vicinity of the outlet baffle. The tank should be cleaned whenever: (1) the bottom of the scum layer is within 3 in. of the bottom of the outlet device; or (2) the sludge level is within 8 in. of the bottom of the outlet device. The efficiency of suspended solids removal may start to decrease before these conditions are reached.

Scum can be measured with a stick to which a weighted flap has been hinged, or with any device that can be used to feel the bottom of the scum mat. The stick is forced through the mat, the hinged flap falls into a horizontal position, and the stick is raised until resistance from the bottom of the scum is felt. With the same tool, the distance to the bottom of the outlet device can be determined.

A long stick wrapped with rough, white toweling and lowered to the bottom of the tank will show the depth of sludge and the liquid depth of the tank. The stick should be lowered behind the outlet device to avoid scum particles. After several minutes, the sludge layer can be distinguished by sludge particles clinging to the toweling.

Other methods for measuring sludge include connecting a small pump to a clear plastic line and lowering the line until the pump starts to draw high solids concentrations.

Following is a list of considerations pertaining to septic tank operation and maintenance:

1. Climbing into septic tanks can be very dangerous, as the tanks are full of toxic gases. When using the manhole, take every precaution possible, i.e., do not lower an individual into the tank without a proper air supply, and safety rope tied around chest or waist.

2. The manhole, not the inspection pipe, should be used for pumping so as to minimize the risk of harm to the inlet and outlet baffles.

3. Leaving solids in the septic tank to aid in starting the system is not necessary.

4. When pumped, the septic tank must not be disinfected, washed, or scrubbed.

5. Special chemicals are not needed to start activity in a septic tank.

6. Special additives are not needed to improve or assist tank operation once it is under way. No chemical additives are needed to "clean" septic tanks. Such compounds may cause sludge bulking and decreased sludge digestion. However, ordinary amounts of bleaches, lyes, caustics, soaps, detergents, and drain cleaners do not harm the system. Other preparations, some of which claim to eliminate the need for septic tank pumping, are not necessary for proper operation and are of questionable value.

7. Materials not readily decomposed (e.g., sanitary napkins, coffee grounds, cooking fats, bones, wet-strength towels, disposable diapers, facial tissues, cigarette butts) should never be flushed into a septic tank. They will not degrade in the tank, and can clog inlets, outlets, and the disposal systems.

6.2.8 Considerations for Multi-Home and Commercial Wastewater

6.2.8.1 General

In some instances, a septic tank can serve several homes, or a commercial/institutional user such as a school, store, laundry, or restaurant. Whereas septic tanks for single-family homes must handle highly variable flows (i.e., approximately 45% of the total household flow occurs in the peak four hours), commercial systems must also be able to treat continuous wastewater flows for 8-16 hours a day as well as peak loadings. In addition, commercial wastewaters may present special problems that need to be handled prior to discharge to the septic tank (i.e., grease removal for restaurant wastewaters, and lint removal for laundry wastewater).

As explained previously, septic tanks of two compartments give better results than single-compartment tanks. Although single-compartment tanks are acceptable for small household installations, tanks with two compartments should be provided for the larger institutional systems. Tanks with more than two compartments are not used frequently.

Multiple-compartment tanks for commercial/institutional flows should have the same design features as single-family home tanks discussed above. These include: compartments separated by walls with ports or slits at proper elevations, proper venting, access to all compartments, and proper inlet and outlet design and submergence.

The effect of a multiple-compartment tank can be accomplished by using two or more tanks in series. A better construction arrangement, particularly for medium or large installations, is to connect special tank sections together into a unit having single end-walls and two compartments. A unit of four precast tank sections forming two compartments is shown in Figure 6-4.

6.2.8.2 Design

Larger tanks for commercial/institutional flows or for clusters of homes must be sized for the intended flow. Whenever possible with existing facilities, the flow should be metered to obtain accurate readings on average daily flows and flow peaks. For housing clusters, if the total flow cannot be measured, the individually metered or estimated flows (based on the expected population and the generation rate of 45 gal/cap/day (170 l/cap/day) from each house must be summed to determine the design flow. For commercial/institutional applications, consult Chapter 4. For flows between 750 and 1,500 gal per day (2,840 to 5,680 l per day), the capacity of the tank is normally equal to 1-1/2 days wastewater flow. For flows between 1,500 and 15,000 gpd (5,680 to 56,800 lpd), the minimum effective tank capacity can be calculated at 1,125 gal (4,260 l) plus 75% of the daily flow; or

$$V = 1,125 + 0.75Q$$

where:

V = net volume of the tank (gal)
Q = daily wastewater flow (gal)

If garbage grinders are used, additional volume or extra sludge storage may be desired to minimize the frequency of pumping (10).

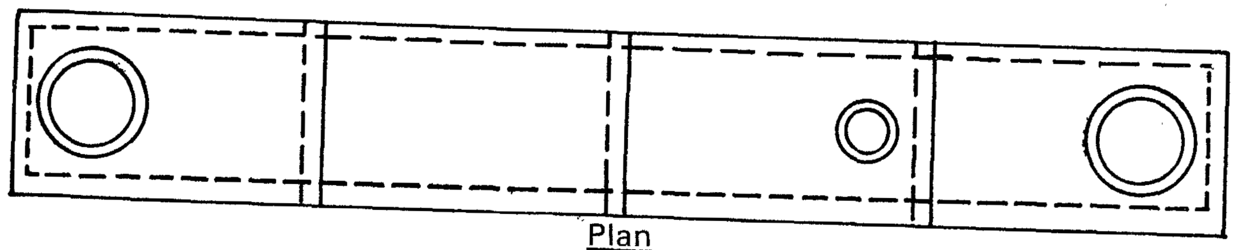
6.3 Intermittent Sand Filters

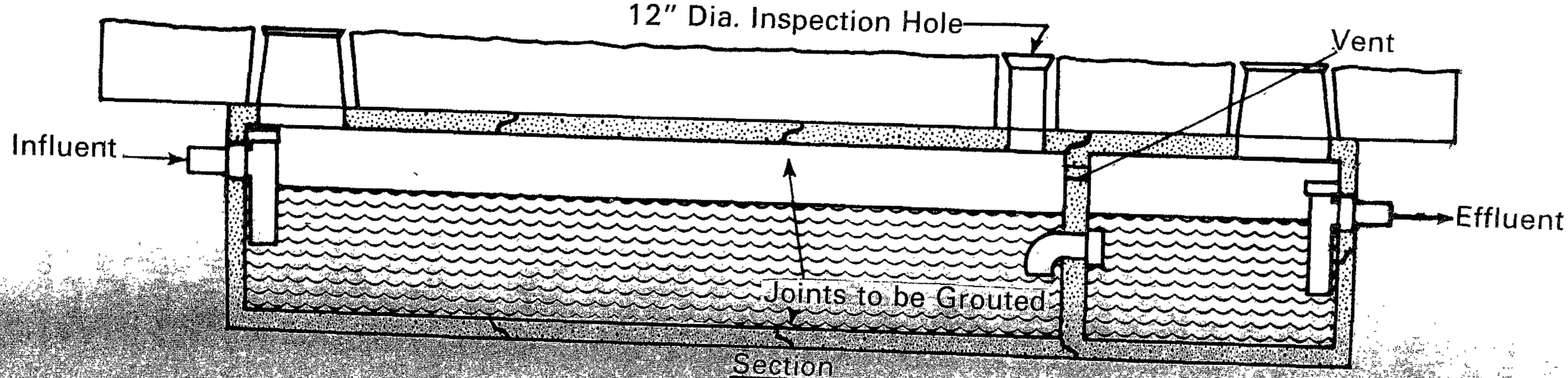
6.3.1 Introduction

Intermittent sand filtration may be defined as the intermittent application of wastewater to a bed of granular material which is underdrained to collect and discharge the final effluent. One of the oldest methods of wastewater treatment known, intermittent sand filtration, if properly designed, operated, and constructed, will produce effluents of very high quality. Currently, many intermittent sand filters are used throughout the United States to treat wastewater from small commercial and institutional developments and from individual

FIGURE 6-4

FOUR PRECAST REINFORCED CONCRETE SEPTIC TANKS COMBINED INTO ONE UNIT FOR LARGE FLOW APPLICATION (10)





homes. The use of intermittent sand filters for upgrading stabilization ponds has also become popular (13).

Intermittent sand filtration is well suited to onsite wastewater treatment and disposal. The process is highly efficient, yet requires a minimum of operation and maintenance. Normally, it would be used to polish effluents from septic tank or aerobic treatment processes and would be followed by disinfection (as required) prior to reuse or disposal to land or surface waters.

6.3.2 Description

Intermittent sand filters are beds of granular materials 24 to 36 in. (61 to 91 cm) deep and underlain by graded gravel and collecting tile. Wastewater is applied intermittently to the surface of the bed through distribution pipes or troughs. Uniform distribution is normally obtained by dosing so as to flood the entire surface of the bed.

Filters may be designed to provide free access (open filters), or may be buried in the ground (buried filters). A relatively new concept in filtration employs recirculation of filter effluent (recirculating filters).

The mechanisms of purification attained by intermittent sand filters are complex and not well understood even today. Filters provide physical straining and sedimentation of solid materials within the media grains. Chemical sorption also plays a role in the removal of some materials. However, successful treatment of wastewaters is dependent upon the biochemical transformations occurring within the filter. Without the assimilation of filtered and sorbed materials by biological growth within the filter, the process would fail to operate properly. There is a broad range of trophic levels operating within the filter, from the bacteria to annelid worms.

Since filters entrap, sorb, and assimilate materials in the wastewater, it is not surprising to find that the interstices between the grains may fill, and the filter may eventually clog. Clogging may be caused by physical, chemical, and biological factors. Physical clogging is normally caused by the accumulation of stable solid materials within or on the surface of the sand. It is dependent on grain size and porosity of the filter media, and on wastewater suspended solids characteristics. The precipitation, coagulation, and adsorption of a vareity of materials in wastewater may also contribute to the clogging problem in some filter operations (14). Biological clogging is due primarily to an improper balance of the intricate biological population within the filter. Toxic components in the wastewater, high organic loading, absence of dissolved oxygen, and decrease in filter temperatures are the most likely causes of microbial imbalances. Accumulation of biological slimes and a decrease in the rate of decomposition of entrapped wastewater contaminants within the filter accelerates filter clogging. All forms of pore clogging likely occur simultaneously throughout the filter bed. The dominant clogging mechanism is dependent upon wastewater characteristics, method and rate of wastewater application, characteristics of the filtering media, and filter environmental conditions.

6.3.3 Application

Intermittent sand filtration is well adapted to onsite disposal. Its size is limited by land availability. The process is applicable to single homes and clusters of dwellings. The wastewater applied to the intermittent filters should be pretreated at least by sedimentation. Septic tanks should be required as a minimum. Additional pretreatment by aerobic biological processes normally results in higher acceptable rates of wastewater application and longer filter runs. Although extensive field experience is lacking to date, the application of pretreated graywaters to intermittent sand filters may be advantageously employed. There is some evidence that higher loading rates and longer filter runs can be achieved with pretreated graywaters.

Site constraints should not limit the application of intermittent sand filters, although odors from open filters receiving septic tank effluent may require isolation of the process from dwellings. Filters are often partially (or completely) buried in the ground, but may be constructed above ground when dictated by shallow bedrock or high water tables. Covered filters are required in areas with extended periods of subfreezing weather. Excessive long-term rainfall and runoff on submerged filter systems may be detrimental to performance, requiring appropriate measures to divert these sources away from the system.

6.3.4 Factors Affecting Performance

The degree of stabilization attained by an intermittent sand filter is dependent upon: (1) the type and biodegradability of wastewater applied to the filter, (2) the environmental conditions within the filter, and (3) the design characteristics of the filter.

Reaeration and temperature are two of the most important environmental conditions that affect the degree of wastewater purification through an intermittent sand filter. Availability of oxygen within the pores allows for the aerobic decomposition of the wastewater. Temperature directly affects the rate of microbial growth, chemical reactions, adsorption mechanisms, and other factors that contribute to the stabilization of wastewater within the sand media.

Proper selection of process design variables also affects the degree of purification of wastewater by intermittent filters. A brief discussion of those variables is presented below.

6.3.4.1 Media Size and Distribution

The successful use of a granular material as a filtering media is dependent upon the proper choice of size and uniformity of the grains. Filter media size and uniformity are expressed in terms of "effective size" and "uniformity coefficient." The effective size is the size of the grain, in millimeters, such that 10% by weight are smaller. The uniformity coefficient is the ratio of the grain size that has 60% by weight finer than itself to the size which has 10% finer than itself. The effective size of the granular media affects the quantity of wastewater that may be filtered, the rate of filtration, the penetration depth of particulate matter, and the quality of the filter effluent. Granular media that is too coarse lowers the retention time of the applied wastewater through the filter to a point where adequate biological decomposition is not attained. Too fine a media limits the quantity of wastewater that may be successfully filtered, and will lead to early filter clogging. This is due to the low hydraulic capacity and the existence of capillary saturation, characteristic of fine materials. Metcalf and Eddy (15) and Boyce (16) recommended that not more than 1% of the media should be finer than 0.13 mm. Many suggested values for the effective size and uniformity coefficient exist in the literature (10)(17)(18)(19)(20). Recommended filter media effective sizes range from a minimum of 0.25 mm up to approximately 1.5 mm. Uniformity coefficients (UC) for intermittent filter media normally should be less than 4.0.

Granular media other than sand that have been used include anthracite, garnet, ilmenite, activated carbon, and mineral tailings. The media selected should be durable and insoluble in water. Total organic matter should be less than 1%, and total acid soluble matter should not exceed 3%. Any clay, loam, limestone, or organic material may increase the initial adsorption capacity of the sand, but may lead to a serious clogging condition as the filter ages.

Shapes of individual media grains include round, oval, and angular configurations. Purification of wastewater infiltrating through granular media is dependent upon the adsorption and oxidation of organic matter in the wastewater. To a limiting extent, this is dependent on the shape of the grain; however, it is more dependent on the size distribution of the grains, which is characterized by the UC.

The arrangement or placement of different sizes of grains throughout the filter bed is also an important design consideration. A homogeneous bed of one effective size media does not occur often due to construction practices and variations in local materials. In a bed having fine media layers placed above coarse layers, the downward attraction of wastewater is not as great due to the lower amount of cohesion of the water in the larger pores (21). The coarse media will not draw the water out of the fine media, thereby causing the bottom layers of the fine material to remain saturated with water. This saturated zone acts as a water seal, limits oxidation, promotes clogging, and reduces the action of the filter to a mere straining mechanism. The use of media with a UC of less than 4.0 minimizes this problem.

The media arrangement of coarse over fine appears theoretically to be the most favorable, but it may be difficult to operate such a filter due to internal clogging throughout the filter.

6.3.4.2 Hydraulic Loading Rate

The hydraulic loading rate may be defined as the volume of liquid applied to the surface area of the sand filter over a designated length of time. Hydraulic loading is normally expressed as gpd/ft^2, or cm/day. Values of recommended loading rates for intermittent sand filtration vary throughout the literature and depend upon the effective size of sand and the type of wastewater. They normally range from 0.75 to 15 gpd/ft^2 (0.3 to 0.6 $m^3/m^2/d$).

6.3.4.3 Organic Loading Rate

The organic loading rate may be defined as the amount of soluble and insoluble organic matter applied per unit volume of filter bed over a designated length of time. Organic loading rates are not often reported in the literature. However, early investigators found that the performance of intermittent sand filters was dependent upon the accumulation of stable organic material in the filter bed (14)(21). To account for this, suggested hydraulic loading rates today are often given for a particular type of wastewater. Allowable loading rates increase with the degree of pretreatment. A strict relationship establishing an organic loading rate, however, has not yet been clearly defined in the literature.

6.3.4.4 Depth of Media

Depths of intermittent sand filters were initially designed to be 4 to 10 feet; however, it was soon realized at the Lawrence Experimental Station (21) that most of the purification of wastewater occurred within the top 9 to 12 in. (23 to 30 cm) of the bed. Additional bed depth did not improve the wastewater purification to any significant degree. Most media depths used today range from 24 to 42 in. (62 to 107 cm). The use of shallow filter beds helps to keep the cost of installation low. Deeper beds tend to produce a more constant effluent quality, are not affected as severely by rainfall or snow melt (22), and permit the removal of more media before media replacement becomes necessary.

6.3.4.5 Dosing Techniques and Frequency

Dosing techniques refer to methods of application of wastewater to the intermittent sand filter. Dosing of intermittent filters is critical to the performance of the process. The system must be designed to insure uniform distribution of wastewater throughout the filter cross-section. Sufficient resting must also be provided between dosages to obtain aerobic conditions. In small filters, wastewater is applied in doses large enough to entirely flood the filter surface with at least 3 in. (8 cm) of water, thereby insuring adequate distribution. Dosing frequency is dependent upon media size, but should be greater with smaller doses for coarser media.

Dosing methods that have been used include ridge and furrow application, drain tile distribution, surface flooding, and spray distribution methods. Early sand filters for municipal wastewater were surface units that normally employed ridge and furrow or spray distribution methods. Intermittent filters in use today are often built below the ground surface and employ tile distribution.

The frequency of dosing intermittent sand filters is open to considerable design judgement. Most of the earlier studies used a dosing frequency of 1/day. The Florida studies investigatged multiple dosings and concluded that the BOD removal efficiency of filters with media effective size greater than 0.45 mm is appreciably increased when the frequency of loading is increased beyond twice per day (23). This multiple dosing concept is successfully used in recirculating sand filter systems in Illinois (24), which employ a dosing frequency of once every 30 min.

6.3.4.6 Maintenance Techniques

Various techniques to maintain the filter bed may be employed when the bed becomes clogged. Some of these include: (1) resting the bed for a period of time, (2) raking the surface layer and thus breaking the inhibiting crust, or (3) removing the top surface media and replacing it with clean media. The effectiveness of each technique has not been clearly established in the literature.

6.3.5 Filter Performance

A summary of the performance of selected intermittent sand filters treating household wastwaters appears in Table 6-4, 6-5, and 6-6. These tables illustrate that intermittent filters produce high-quality effluents with respect to BOD_5 and suspended solids. Normally, nitrogen is transformed almost completely to the nitrate form provided the filter remains aerobic. Rates of nitrification may decrease in winter months as temperatures fall. Little or no denitrification should occur in properly operated intermittent filters.

Total and ortho-phosphate concentrations can be reduced up to approximately 50% in clean sand; but the exchange capacity of most of the sand as well as phosphorus removal after maturation is low. Use of calcareous sand or other high-aluminum or iron materials intermixed within the sand may produce significant phosphorus removal. Chowdhry (28) and Brandes, et al. (23), reported phosphorus removals of up to 90% when additions of 4% "red mud" (high in Al_2O_3 and Fe_2O_3) were made to a medium sand. Intermittent filters are capable of reducing total and fecal coliforms by 2 to 4 logs, producing effluent values ranging from 100 to 3,000 per 100 ml and 1,000 to 100,000/100 ml for fecal and total coliforms, respectively (2)(19)(28).

6.3.6 Design Criteria

6.3.6.1 Buried Filters

Table 6-7 summarizes design criteria for subsurface intermittent sand filters.

Hydraulic loading of these filters is normally equal to or less than 1.0 gpd/ft^2 (0.04 m^3/m^2/d) for full-time residences. This value is similar to loading rates for absorption systems in sandy soils after

TABLE 6-4

PERFORMANCE OF BURIED INTERMITTENT FILTERS - SEPTIC TANK EFFLUENT

Filter Characteristics				Effluent Characteristics				
Effective Size	Uniformity Coefficient	Hydraulic Loading	Depth	BOD	SS	NH_3^-N	NO_3^-N	Reference
mm		gpd/ft^2	in.	mg/l	mg/l	mg/l	mg/l	
0.24	3.9	1	30	2.0	4.4	0.3	25	25
0.30	4.1	1	30	4.7	3.9	3.8	23	25
0.60	2.7	1	30	3.8	4.3	3.1	27	25
1.0	2.1	1	30	4.3	4.9	3.7	24	25
2.5	1.2	1	30	8.9	12.9	6.7	18	25
0.17	11.8	0.2	39	1.8	11.0	1.0	32	22
0.23 - 0.36	2.6 - 6.1	1.15	24	4	12	0.7	17	19

TABLE 6-5

PERFORMANCE OF FREE ACCESS INTERMITTENT FILTERS

Source	Filter Characteristics: Effective Size (mm)	Filter Characteristics: Unif. Coeff.	Filter Characteristics: Hydraulic Loading (gpd/ft^2)	Depth (in.)	Dose Freq. (per day)	Effluent Quality: BOD (mg/l)	Effluent Quality: SS (mg/l)	Effluent Quality: NH_3^-N (mg/l)	Effluent Quality: NO_3^-N (mg/l)	Filter Run (months)	
Septic Tank	0.23 - 0.26	-	4.5	60	-	23[a]	-	8	32	6 - 9[b]	21
Septic Tank	0.41	-	2.3	60	-	11[a]	-	3	46	6 - 9[b]	21
Trick Filter	0.27	-	11.4	60	-	17[a]	-	2	29	6[b]	21
Trick Filter	0.41	-	14.0	60	-	18[a]	-	2	33	12[b]	21
Pri	0.25	-	2.75	30	1	6	6	5	19	4.5	23
Primary	0.25	-	4.7	30	2	3	8	2	22	36	23
Primary	1.04	-	-	30	2	28	36	10	13	>54	23
Primary	1.04	-	14	30	24	4	9	3	17	>54	23
Septic Tank	0.45	3.0	5	30	3-6	8	4	3	25	3	2
Extended Aer.	0.19	3.3	3.8	30	3-6	3	9	0.3	34	[illegible]	2
Lagoon(Summer)	0.19	9.7	9.1	36	1	2	3	0.5	4.0	1	13
Lagoon(Winter)	0.19	9.7	9.1	36	1	9.4	9.6	4.6	1.0	4	[illegible]

[a] Estimated from "oxygen consumed."

[b] Weekly raking 3 inches deep.

TABLE 6-6

PERFORMANCE OF RECIRCULATING INTERMITTENT FILTERS[a]

Filter Characteristics						Effluent Quality				
Effective Size	Unif. Coeff.	Hydraulic Loading	Depth	Recirculation Ratio	Dose	BOD	SS	NH_3-N	Mtnce.	Ref.
mm		gpd/ft^2	in.	r/Q		mg/l	mg/l	mg/l		
0.6 - 1.0	2.5	-	36	4:1	5-10 min every 30 min	4	5	-	Weed/Rake as Req'd	24
0.3 - 1.5	3.5	3.0 - 5.0[b]	24	3:1 - 5:1	20 min every 2-3 hr	15.8[c]	10.0[c]	8.4[c]	Rake Weekly	26
1.2	2.0	3.0[b]	36	4:1	5 min every 30 min	4	3	-	Weed as Req'd	27

[a] Septic tank effluent.

[b] Based on forward flow.

[c] Average for 12 installations (household flow to 6,500 gpd plant).

TABLE 6-7

DESIGN CRITERIA FOR BURIED INTERMITTENT FILTERS

Item	Design Criteria
Pretreatment	Minimum level - sedimentation (septic tank or equivalent)
Hydraulic Loading	
All year	<1.0 gpd/ft^2
Seasonal	<2.0 gpd/ft^2
Media	
Material	Washed durable granular material (less than 1 percent organic matter by weight)
Effective size	0.50 to 1.00 mm
Unif. Coeff.	<4.0 (<3.5 preferable)
Depth	24 to 36 inches
Underdrains	
Material	Open joint or perforated pipe
Slope	0.5 to 1.0 percent
Bedding	Washed durable gravel or crushed stone (1/4 to 1-1/2 in.)
Venting	Upstream end
Distribution	
Material	Open joint or perforated pipe
Bedding	Washed durable gravel or stone (3/4 to 2-1/2 in.)
Venting	Downstream end
Dosing	Flood filter; frequency greater than 2 per day

equilibrium conditions are obtained. When filters are designed for facilities with seasonal occupation, hydraulic loading may be increased to 2.0 gpd/ft^2 (0.08 m^3/m^2/d) since sufficient time will be available for drying and restoring the infiltrative surface of the bed.

The effective size of media for subsurface filters ranges from 0.35 to 1.0 mm with a UC less than 4.0, and preferably less than 3.5. Finer media will tend to clog more readily, whereas coarser media may result in poorer distribution and will normally produce a lower effluent quality.

Distribution and underdrains are normally perforated or open-joint pipe with a minimum 4-in. (10-cm) diameter. The distribution and underdrain lines are surrounded by at least 8 in. of washed durable gravel or crushed stone. For distribution lines, the gravel or stone is usually smaller than 2-1/2 in. (6 cm) but larger than 3/4 in. (2 cm), whereas the size range of the gravel or stone for the underdrains is between 1-1/2 to 1/4 in. (3.8 to 0.6 cm). Slopes of underdrain pipe range from 0.5 to 1%. With dosing, there would be no requirement for slopes on distribution piping.

Proper dosing to the filter is critical to its successful performance. The dosing system is designed to flood the entire filter during the dosing cycle. A dosing frequency of greater than two times per day is recommended. Details on design and construction of dosing chamber facilities appear in Chapter 8.

6.3.6.2 Free Access Filters (Non-Recirculating)

Design criteria for free access filters are presented in Table 6-8.

Hydraulic loading to these filters depends upon media size and wastewater characteristics. Septic tank effluent may be applied at rates up to 5 gpd/ft^2 (0.2 m^3/m^2/d), whereas a higher quality pretreated wastewater may be applied at rates as high as 10 gal/d ft^2 (40 cm/d). Selection of hydraulic loading will also be influenced by desired filter run times (see Section 6.3.8). Higher acceptable loadings on these filters as compared to subsurface filters relates primarily to the accessibility of the filter surface for maintenance.

Media characteristics and underdrain systems for free access filters are similar to those for subsurface filters. Distribution is often provided through pipelines and directed on splash plates located at the center or corners of the sand surface. Occasionally, troughs or spray nozzles are

TABLE 6-8

DESIGN CRITERIA FOR FREE ACCESS INTERMITTENT FILTERS

Item	Design Criteria
Pretreatment	Minimum level - sedimentation (septic tank or equivalent)
Hydraulic Loading	
Septic tank feed	2.0 to 5.0 gpd/ft^2
Aerobic feed	5.0 to 10.0 gpd/ft^2
Media	
Material	Washed durable granular material (less than 1 percent organic matter by weight)
Effective size	0.35 to 1.00 mm
Unif. Coeff.	<4.0 (<3.5 preferable)
Depth	24 to 36 inches
Underdrains	
Material	Open joint or perforated pipe
Slope	0.5 to 1.0 percent
Bedding	Washed durable gravel or crushed stone (1/4 to 1-1/2 in.)
Venting	Upstream end
Distribution	Troughs on surface; splash plates at center or corners; sprinkler distribution
Dosing	Flood filter to 2 inches; frequency greater than 2 per day
Number	
Septic tank feed	Dual filters, each sized for design flow
Aerobic feed	Single filter

employed as well, and ridge and furrow application has been successful during winter operation in severe climatic conditions. Dosing of the filter should provide for flooding the bed to a depth of approximately 2 in. Dosing frequency is usually greater than two times per day. For coarser media (greater than 0.5 mm), a dosing frequency greater than 4 times per day is desirable. Design criteria for dosing chambers, pumps, and siphons are found in Chapter 8.

The properties of the wastewater applied affect the clogging characteristics of the filter and, therefore, the methods of filter maintenance. Dual filters, each designed to carry the design flow rate, may be desirable when treating septic tank effluent to allow sufficient resting after clogging (see Section 6.3.8).

6.3.6.3 Recirculating Filters

Proposed design criteria for recirculating intermittent sand filters are presented in Table 6-9 (24)(26). These free access filters employ a recirculation (dosing) tank between the pretreatment unit and filter with provision for return of filtered effluent to the recirculation tank.

Hydraulic loading ranges from 3 to 5 gpd/ft^2 (0.12 to 0.20 m^3/m^2/d) depending on media size. Media size range is from 0.3 to 1.5 mm, the coarser sizes being recommended (23)(26). Underdrain and distribution arrangements are similar to those for free access filters. Recirculation is critical to effective operation, and a 3:1 to 5:1 recirculation ratio (Recycle: Forward Flow) is preferable. Pumps should be set by timer to dose approximately 5 to 10 min per 30 min. Longer dosing cycles may be desirable for larger installations - 20 min every 2 to 3 hr. Dosing should be at a rate high enough to insure flooding of the surface to greater than 2 in. (5 cm). Recirculation chambers are normally sized at 1/4 to 1/2 the volume of the septic tank.

6.3.7 Construction Features

6.3.7.1 Buried Filters

A typical plan and profile of a buried intermittent sand filter are depicted in Figure 6-5. The filter is placed within the ground with a natural topsoil cover in excess of 10 in. (25 cm) over the crown of the distribution pipes. The filter must be carefully constructed after excavation and the granular fill settled by flooding. Distribution and underdrain lines should be constructed of an acceptable material with a minimum diameter of 4 in. (10 cm). The tile is normally laid with open

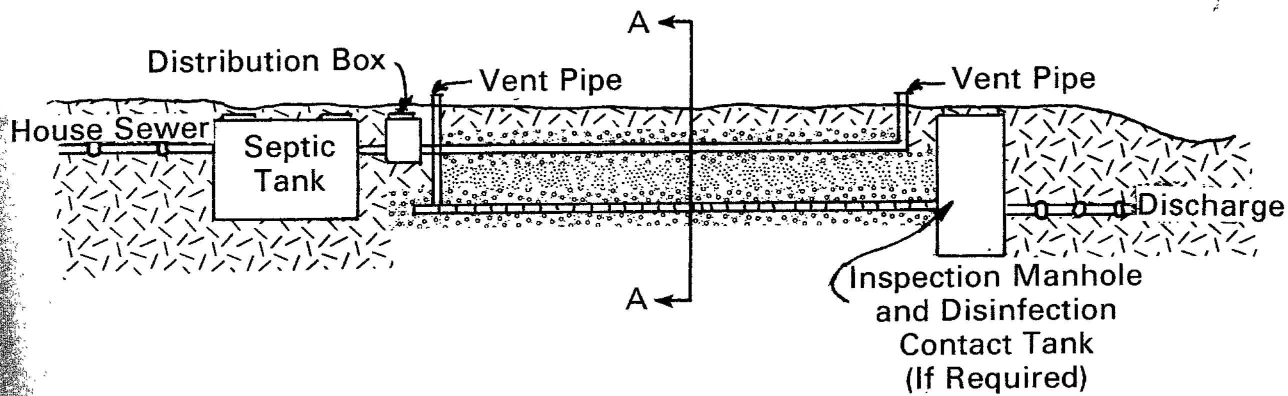
TABLE 6-9

DESIGN CRITERIA FOR RECIRCULATING INTERMITTENT FILTERS

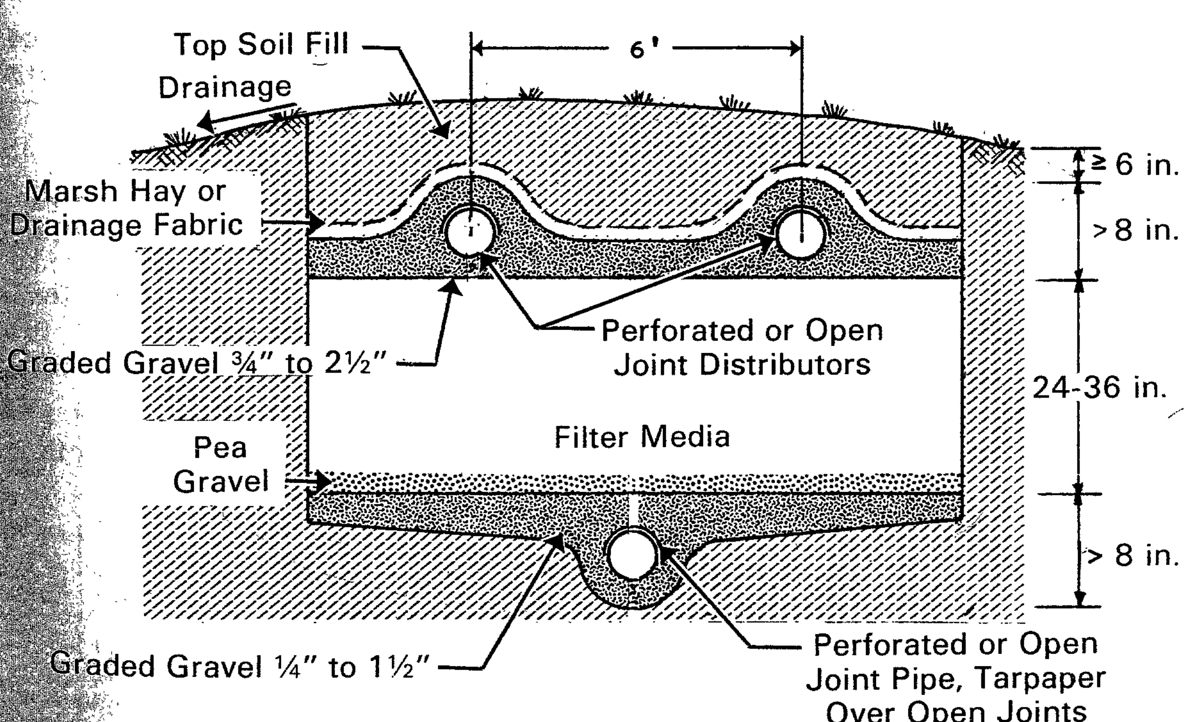
Item	Design Criteria
Pretreatment	Minimum level - sedimentation (septic tank or equivalent)
Hydraulic Loading	3.0 to 5.0 gpd/ft^2 (forward flow)
Media	
Material	Washed durable granular material (less than 1 percent organic matter by weight)
Effective size	0.3 to 1.5 mm
Unif. Coeff.	<4.0 (<3.5 preferable)
Depth	24 to 36 inches
Underdrains	
Material	Open joint or perforated pipe
Slope	0.5 to 1.0 percent
Bedding	Washed durable gravel or crushed stone (1/4 to 1-1/2 in.)
Venting	Upstream end
Distribution	Troughs on surface; splash plates at center or corners; sprinkler distribution
Recirculation Ratio	3:1 to 5:1 (5:1 preferable).
Dosing	Flood filter to approx. 2 inches; pump 5 to 10 min per 30 min; empty recirculation tank in less than 20 min
Recirculation Tank	Volume equivalent to at least one day's raw wastewater flow

FIGURE 6-5

TYPICAL BURIED INTERMITTENT FILTER INSTALLATION



Profile



Section A-A

joints with sections spaced not less than 1/4 in. (0.6 cm) or greater than 1/2 in. (1.3 cm) apart. If continuous pipeline is used, conventional perforated pipe will provide adequate distribution and collection of wastewater within the filter.

The underdrain lines are laid to grade (0.5 to 1%) and one line is provided for each 12 ft (3.6 m) of trench width. Underdrains are provided with a vent pipe at the upstream end extending to the ground surface. The bedding material for underdrain lines is usually a minimum of 10 in. (25 cm) washed graded gravel or stone with sizes ranging from 1/4 to 1-1/2 in. (0.6 to 3.8 cm). The gravel or stone may be overlain with a minimum of 3 in. (8 cm) of washed pea gravel (1/4- to 3/8-in. [0.6 to 1.0 cm] stone) interfacing with the filter media.

The distribution lines should be level and are normally spaced at 3-ft (0.9 m) centers. Distribution lines should be vented at the downstream end with vertical risers to the ground surface. Approximately 10 in. (25 cm) of graded gravel (3/4- to 2-1/2-in. [1.9- to 6.3-cm] size) is usually employed for bedding of distribution lines. Marsh hay, washed pea gravel, or drainage fabric should be placed between the bedding material and the natural topsoil.

The finished grade over the filter should be mounded so as to provide drainage of rainfall away from the filter bed. A grade of approximately 3 to 5%, depending upon topsoil characteristics, would be sufficient.

Any washed, durable granular material that is low in organic matter may be used for filter medium. Mixtures of sand, slag, coal, or other materials have been used to enhance the removal of selected pollutants and to extend filter life. Care must be taken, however, to insure that the media does not stratify with fine layers over coarse.

Design and construction of the dosing chamber and pump or siphon employed for proper application of wastewater to the filter are described in Chapter 8 of this manual.

6.3.7.2 Free Access Filters

The plan and profile of a typical free access filter appear in Figure 6-6. These filters are often built within the natural soil, but may also be constructed completely above the ground surface. They are usually surrounded by sidewalls, often of masonry construction, to prevent earth from washing into the filter media and to confine the flow of wastewater. Where severe climates are encountered, filter walls should

FIGURE 6-6

TYPICAL FREE ACCESS INTERMITTENT FILTER